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54 Verfahren und Vorrichtung zur Stützung der Trägheitsnavigation eines ein entferntes Ziel autonom ansteuernden Flugkörpers

57 Ein Verfahren zur Stützung der Trägheitsnavigation eines ein entferntes Ziel autonom ansteuernden Flugkörpers benutzt einen unter einem endlichen Winkel schräg zur Flugrichtung blickenden, das überflogene Gelände erfassenden, bildzeugenden Sensor, der Geländedaten liefert, aus denen durch Vergleich mit bekannten Geländedaten eine Position des Flugkörpers gewonnen wird, wobei wiederum diese Position mit der von der Trägheitsnavigation bestimmten Position verglichen und das Trägheitsnavigationssystem nach Maßgabe dieses Vergleichs korrigiert wird. Durch den bildzeugenden Sensor werden während der Bewegung des Flugkörpers über dem Gelände aus verschiedenen Flugkörperpositionen laufend Bilder des überflogenen Geländes zur Erzeugung einer Bildsequenz aufgenommen. Diese Bilder werden elektronisch gespeichert. Aus gespeicherten Bildern und den zugehörigen, aus der Trägheitsnavigation erhaltenen Positionsdifferenzen des Flugkörpers wird durch Stereobild-Auswertung eine dreidimensionale Darstellung des Geländes berechnet. Die berechnete Darstellung des Geländes wird mit einem gespeicherten Modell des Geländes verglichen und daraus die Position und der Kurs des Flugkörpers bestimmt.

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lung.  
(d) Mitteln zum Speichern eines dreidimensionalen

lung des überflogenen Geländes. Diese dreidimensionale Darstellung des überflogenen Geländes wird mit ei-

## Technisches Gebiet

Die Erfindung betrifft ein Verfahren zur Stützung der Trägheitsnavigation eines ein entferntes Ziel autonom ansteuernden Flugkörpers mittels eines unter einem endlichen Winkel seitwärts zur Flugrichtung blickenden, das überflogene Gelände erfassenden, bildzeugenden Sensors, der Geländedaten liefert, aus denen durch Vergleich mit bekannten Geländedaten eine Position des Flugkörpers gewonnen wird, wobei wiederum diese Position mit der von der Trägheitsnavigation bestimmten Position verglichen und das Trägheitsnavigationssystem nach Maßgabe dieses Vergleichs korrigiert wird.

Die Erfindung betrifft weiterhin eine Vorrichtung zur Stützung der Trägheitsnavigation eines ein entferntes Ziel autonom ansteuernden Flugkörpers zur Durchführung dieses Verfahrens.

## Zugrundeliegender Stand der Technik

Niedrig fliegende, autonome Flugkörper sind beispielsweise sog. "Marachflugkörper". Die Navigation solcher Flugkörper basiert primär auf Trägheitsnavigation. Eine mit Kreisel- und Beschleunigungsmessern aufgebaute Trägheitssensor-Einheit liefert Daten über Position, Geschwindigkeit und Kurs des Flugkörpers. Solche Trägheitssensor-Einheiten weisen eine Drift auf. Die angezeigte Position und der Kurs des Flugkörpers ändern sich langsam. Die Fehler werden umso größer, je länger die Flugzeit dauert. Es ist daher erforderlich, von Zeit zu Zeit Position und Kurs des Flugkörpers zu kontrollieren und Korrekturen an der Trägheitssensor-Einheit anzubringen.

Es ist möglich, zur Positions-Bestimmung Signale von Navigations-Satelliten (GPS) zu empfangen und zu verarbeiten. Die darauf beruhende Positions-Bestimmung gewährleistet hohe Präzision. Es wird jedoch bei militärischem Gerät häufig gefordert, daß die Navigation absolut autonom erfolgt.

Es ist weiter bekannt, das überflogene Gelände mittels eines an Bord des Flugkörpers angeordneten Radargeräts abzutasten. Diese Art der Positions-Kontrolle erfüllt aber nicht die Forderung nach absoluter Passivität, also des Verbots der Emission verräterischer, aktiver Strahlung.

des nicht so stark bemerkbar, wie das der Fall wäre, wenn die Korrelations-Funktion über den gesamten Bildinhalt hinweg gebildet würde. Der Rechenaufwand und die erforderliche Speicherkapazität werden gegenüber der letzteren Möglichkeit wesentlich verringert.

Die Lage der Punkte A und B zu der fehlerbehafteten Position 42 ist bekannt. Aus der Berechnung der dreidimensionalen Geländestruktur ergeben sich die Abstände der Position 42 von den Punkten A bzw. B des beobachteten Geländes. Aus den nunmehr bekannten, durch die Korrelations-Funktion bestimmten Punkten A' und B' auf der Landkarte kann dann der Punkt 34 auf der Landkarte, d. h. die wahre Position bestimmt werden. Die wahre Position 34 liegt zu den "Landkartenfesten" Punkten A' und B' genau so wie die von der Trägheitsnavigation gelieferte Position 42 zu den Punkten A und B im beobachteten Gelände.

Wenn die Position des Flugkörpers auf die beschriebene Weise bestimmt und die Trägheitssensor-Einheit entsprechend justiert ist, wird die weitere Bewegung der Bildpunkte quasi-kontinuierlich verfolgt. Bildpunkte werden durch kleine, möglichst kontrastreiche "Mikromuster" von z. B. 3 x 3 Pixeln definiert. Durch den Sensor werden Bilder in einem

hängen stark von der Lage dieser Objekte zum Flugkörper ab. Das Erfordernis einer eindeutigen Identifizierbarkeit bedingt einen aufwändigen Erkennungsprozeß. Abhängig von der Blickrichtung kann es unmöglich sein, zum Zwecke der Identifizierung des Objekts den Bildinhalt unmittelbar mit einem gespeicherten Modell des Objekts zu vergleichen. Vielmehr muß bei schräger Blickrichtung über eine perspektivische Transformation des flugkörperfesten gespeicherten Geländemodells in die Blickebene ein quantitativer Vergleich des erwarteten mit dem gesehenen Bildinhalt durchgeführt werden. Erst mit Hilfe dieses Vergleichs kann die Position und der Kurs bestimmt und ggf. korrigiert werden.

Zwischen den Stütz-Objekten muß der Flugkörper "blind" nur mit der Trägheitsnavigation navigieren. Wenn die Stütz-Objekte nahe beieinander angeordnet sind, kann infolge der driftheftigen Positions-Abweichung eine Verwechslung von ähnlich aussehenden Objekten stattfinden. Fällt ein Stütz-Objekt aus, dann kann die Positions-Abweichung so groß werden, daß das übernächste Stütz-Objekt nicht mehr gefunden wird.

Die DE-A-34 12 533 beschreibt einen abbildenden Sensor für dreidimensionale Szenanerkennung, insbesondere für die Anwendung in der Industrieautomation. Mit einem bewegten, bildzeugenden Sensor wird eine Sequenz von Bildern aus verschiedenen Richtungen aufgenommen. Dabei werden Paare von Bildern erzeugt, aus denen ein stereoskopisches Bild der aufgenommenen Szene gewonnen werden kann. Die Bildverarbeitung erfolgt mittels eines parallelverarbeitenden, digitalen Netzwerkes zur Ausführung schneller Korrelations-Vergleiche von Bildausschnitten.

Die EP-A-0 122 048 beschreibt einen parallel arbeitenden Datenprozessor.

## Offenbarung der Erfindung

Der Erfindung liegt die Aufgabe zugrunde, ein Verfahren der eingangs genannten Art zur Stützung der Trägheitsnavigation eines ein entferntes Ziel autonom ansteuernden Flugkörpers so auszugestalten, daß

- die von dem bildzeugenden Sensor gelieferte Information über das Gelände bestmöglich genutzt wird,
- die Stützung der Trägheitsnavigation durch diese Information quasi-kontinuierlich erfolgt, und
- die Stützung unabhängig von dem Vorhandensein markanter Stütz-Objekte in dem Gelände

berechnet werden. In gleicher Weise wird für alle durch das Gesichtsfeld hindurchlaufenden, betrachteten Mikromuster verfahren. Dadurch wird ständig eine dreidimensionale Darstellung des vom Gesichtsfeld des Sensors überstrichenen Geländes erhalten.

Anhand der Mikromuster können kontrastreiche Fenster in dem beobachteten Gelände, die für die Stützung der Trägheitsnavigation benutzt werden, von Bild zu Bild ständig verfolgt werden. Die quasi-kontinuierlich berechnete dreidimensionale Darstellung des Geländes in dem Fenster wird laufend mit einem gespeicherten Geländemodell verglichen. Daraus kann wieder durch Bildung einer Korrelations-Funktion zwischen dieser Darstellung des Geländes und dem Geländemodell über das Fenster in der oben beschriebenen Weise ständig die wahre Position des Flugkörpers ermittelt werden. Dabei weichen sich die Berechnung der dreidimensionalen Darstellung des Geländes und die Korrektur der von der Trägheitsnavigation gelieferten Position ständig ab. Die von der Trägheitsnavigation angegebene Flugbahn weicht dadurch nur geringfügig von der wahren Flugbahn ab. Dementsprechend kann sich die Berechnung der Korrelations-Funktion für die Bestimmung

eine Projektion der aus den verschiedenen Mikromustern erhaltenen dreidimensionalen Geländedarstellung auf eine horizontale Ebene. Dadurch wird eine zweidimensionale Geländedarstellung ähnlich einer Landkarte erhalten zum Vergleich mit einem ebenfalls zweidimensionalen, landkartenartigen Geländemodell, das in dem Flugkörper gespeichert ist.

Eine dritte Rechnerstufe 62 bewirkt einen Vergleich der aus den Bildern des Sensors 56 in der beschriebenen Weise gewonnenen Geländedarstellung mit einem Geländemodell, das in einem Speicher 64 gespeichert ist. Die Rechnerstufe liefert die Verschiebung der aus den Bildern des Sensors 56 gewonnenen Geländedarstellung (im Koordinatensystem des Geländemodells) gegenüber dem Geländemodell. Daraus werden in einem Navigationsrechner 66 in der unter Bezugnahme auf Fig. 3 beschriebenen Weise die wahre Position und der wahre Kurs des Flugkörpers in dem Geländemodell (der Landkarte) bestimmt. Aus den Abweichungen von Position und Kurs des Flugkörpers werden Korrekturwerte für die Tragheitsrechner-Einheit abgeleitet.

Fig. 5 veranschaulicht die Bildverarbeitung von Mikromustern im Bild des Geländes mittels des Parallelrechners 58.

In der schematischen Darstellung von Fig. 5 sind mit 68 Speicherelemente bezeichnet, in denen Bildelemente des von dem Sensor 56 erfaßten Bildes gespeichert sind. Fig. 5 zeigt drei Zeilen solcher Speicherelemente 68, in denen die Bildelemente dreier Zeilen des Bildes gespeichert sind. Der Parallelrechner 58, der die erste Rechnerstufe bildet, enthält eine eindimensionale Anordnung von Prozessor-Elementen 70. Jedem Prozessor-Element 70 ist ein lokaler Speicher 72 mit mehreren Speicherzeilen zugeordnet.

Von den Bildelementen (Pixeln) eines (n-1)-ten Bildes ist ein "Mikromuster" 74 von 3 x 3 Pixeln an seinem Ort in dem (n-1)-ten Bild gespeichert. Zu diesem Zweck ist das (n-1)-te Bild zeilenweise durch die Prozessor-Elemente 70 abgetastet worden. Die Pixel der verschiedenen Zeilen sind in den Speicherelementen in den verschiedenen Ebenen des lokalen Speichers 72 angelegt, also "untereinander" in Fig. 5.

Im n-ten Bild erscheint das gleiche Mikromuster durch die Bewegung des Sensors 56 als Mikromuster 74A an einer anderen Stelle des Bildes, nämlich weiter links in Fig. 5. Es gilt, die Verschiebung zu bestimmen. Das geschieht mittels eines Korrelations-Verfahrens. Um die Länge des Verschiebvektors des Mikromusters 74 von Bild zu Bild zu bestimmen, werden für alle neun Pixel des Mikromusters und eines damit zu vergleichenden 3 x 3-Mikromusters die Betragsdifferenzen gebildet und aufsummiert:

$$K = \sum [\text{Pixel}(B_n) - \text{Pixel}(B_{n-1})].$$

Dadurch wird ein Maß für den Grad der Übereinstimmung zu vergleichender 3 x 3 Mikromuster erhalten. Nimmt man an, daß die Fragestellung des Flugkörpers genau parallel zu den Zeilen der Bilder verläuft, dann braucht man das Mikromuster 74 nur innerhalb der Zeilen nach links in Fig. 5 zu verschieben, bis die Werte von K ein Minimum sind. Es wird das Minimum einer Korrelations-Funktion

$$K(\theta) = \sum [\text{Pixel}(x - \theta, y) - \text{Pixel}(x, y)]$$

mit  $\theta$  als Verschiebe-Koordinate bestimmt. Die Lage des Minimums ist mit  $\theta_{\min}$  bezeichnet. Die Summe wird

dabei wieder über alle neun die ursprüngliche Position und die Suchposition umgebenden Pixel gebildet. Wird  $\theta$  von der Lage des Mikromusters im (n-1)-ten Bild an gerechnet, so ist  $\theta_{\min}$  die Länge des Verschiebvektors 76 für das betreffende Mikromuster zwischen zwei Bildern.  $K(\theta_{\min})$  in ein Maß für die Güte der Übereinstimmung. Die Übereinstimmung ist umso besser, je kleiner  $K(\theta_{\min})$  ist.

Im einzelnen geht diese Prozedur folgendermaßen vor: Die n-te Bild wird zeilenweise verarbeitet. Durch die drei Prozessor-Elemente 80, 82 und 84 werden zunächst die drei Pixel 86, 88 und 90 der ersten Reihe des Mikromusters mit den Pixeln verglichen, die von dem (n-1)-ten Bild her in den Speicherelementen 92, 94 und 96 gespeichert sind. Es werden durch die Prozessor-Elemente 80, 82 und 84 die Differenzen der Pixelinhalte gebildet. Die Beträge dieser Differenzen werden addiert und in einem Speicherelement des lokalen Speichers des mittleren Prozessor-Elements 82 gespeichert. Dann werden in gleicher Weise die Pixel 98, 100, 102 der zweiten Reihe des Mikromusters 74A mit den Pixeln verglichen, die von dem (n-1)-ten Bild her in den Speicherelementen 104, 106 und 108 der lokalen Speicher der Prozessor-Elemente 80, 82 bzw. 84 gespeichert sind. Es werden wieder die Differenzen der Pixelinhalte gebildet. Die Beträge dieser Differenzen werden addiert und zu der im lokalen Speicher des mittleren Speicherelements gespeicherten Differenzen-Summe addiert. Das gleiche geschieht mit den drei Pixeln der dritten Reihe des Mikromusters 74A und den in den Speicherelementen 110, 112 und 114 gespeicherten Pixeln. Auch hier werden die Differenzen der Pixelinhalte und die Summe der Beträge dieser Differenzen gebildet und wieder zu der im lokalen Speicher des Prozessor-Elements 82 von den anderen beiden Zeilen her gespeicherten Differenzen-Summe addiert. Im lokalen Speicher des in bezug auf das Mikromuster 74A mittleren Prozessor-Elements 82 ist daher die Korrelations-Funktion des Mikromusters 74A des Bildes (n-1) mit dem vom Bild n her "darunter" gespeicherten Mikromuster gebildet.

Anschließend wird das Mikromuster 74A "um einen Schritt verschoben", d. h. wird in gleicher Weise mit dem in den lokalen Speichern der Prozessor-Elemente 82, 84 und 116 gespeicherten 3 x 3-Mikromuster verglichen und die Korrelations-Funktion gebildet. Das geht schrittweise weiter, bis der Vergleich mit dem Mikromuster 74 erfolgt. Die Mikromuster 74 und 74A stimmen überein. Die Korrelations-Funktion wird ein Minimum, im Idealfall null. Damit ist das Mikromuster 74 des (n-1)-ten Bildes im Mikromuster 74A des n-ten Bildes "wiedergefunden" worden. Aus der Anzahl der hierzu erforderlichen Schritte, der Variablen  $\theta$ , ergibt sich der Verschiebvektor 76, um den das Mikromuster 74 sich in dem Zeitintervall vom (n-1)-ten Bild zum n-ten Bild im Gesichtsfeld des Sensors 56 verschoben hat. Im vorliegenden Fall erstreckt sich dieser Verschiebvektor in Zeilenrichtung. Der Betrag des Verschiebvektors 76 wird zu der Summe vorher ermittelter Verschiebvektoren des betreffenden Mikromusters addiert. Die letztere Summe war in dem lokalen Speicher des mittleren Prozessor-Elements am Ort des Mikromusters 74 gespeichert. Die neue Summe wird in dem lokalen Speicher des Prozessor-Elements 82 gespeichert. Das Mikromuster 74A wird in den lokalen Speichern der Prozessor-Elemente 80, 82 und 84 gespeichert. Das Mikromuster 74 wird gelöscht.

Es wird jetzt die gleiche Operation mit dem (n+1)-ten Bild und dem n-ten Bild wiederholt. Dieser

Vorgang wiederholt sich mit der Sequenz der Bilder.

Die beschriebene Prozedur kann parallel von allen Prozessor-Elementen 70 der Reihe für alle gültigen Mikromuster einer Zeile durchgeführt werden. In Fig. 5 sind nur drei Zeilen des laufenden Bildes dargestellt. Tatsächlich enthält das Bild wesentlich mehr Zeilen. Diese Zeilen werden nacheinander mittels der Prozessor-Elemente 70 in der beschriebenen Weise mit den darin enthaltenen Mikromustern abgearbeitet.

Zum fortlaufenden Hinzunehmen von neuen Mikromustern aus jüngeren Bildern bedarf es eines Zulassungstests für Mikromuster. Nicht jede 3 x 3-Matrix des Bildes kann und sollte als Mikromuster in der beschriebenen Weise verarbeitet werden. Es gibt homogene oder — im Vergleich zum Bildrauschen — strukturschwache Bereiche im Bild, bei denen die beschriebene Prozedur versagen würde. Daher werden nur diejenigen 3 x 3-Bereiche als gültige Mikromuster zugelassen, die eine vorgegebene Mindest-Auffälligkeit aufweisen und damit hinreichend ausgeprägte und nicht durch Bildrauschen verfälschte Minima der Korrelationsfunktion erwarten lassen. Als Kriterium hierfür dient ein Variationsmaß.

Die Mikromuster wandern auf diese Weise über das Gesichtsfeld des Sensors 56. Für diejenigen Mikromuster, die den hinteren Rand des Gesichtsfeldes erreicht haben, werden die gespeicherten Kenndaten ausgelesen. Diese Kenndaten umfassen die zeitliche Länge des Gesamtweges des Mikromusters, die Länge der gesamten Verschiebestrecke und mindestens den Grauwert 30 der mittleren Pixel. Die zeitliche Länge des Gesamtweges ist die Differenz zwischen dem ersten Auftreten des Mikromusters und seinem letzten Verschleibevorgang. Diese zeitliche Länge ergibt sich als Differenz der zugehörigen Bildnummern dividiert durch die Bildfrequenz. Die Länge der Verschiebestrecke ergibt sich als Differenz der Spaltadressen von erster und letzter Position des Mikromusters. Dabei kann noch eine z. B. parabolische Interpolation zwischen den drei das theoretische Minimum der Korrelationsfunktion umgebenden Stützpunkten der Korrelationsfunktion durchgeführt werden, um diese Länge auf Bruchteile von Pixeln genau zu bestimmen. Die Kenndaten werden an die Rechnerstufe 60 weitergegeben.

Aus den Kenndaten kann dann die jeweilige Stereobasis bestimmt werden. Durch einfache Triangulation ergibt sich der Ort des durch das Mikromuster repräsentierten Objektdetails.

Die zum Schluß durchzuführende Projektion der so gewonnenen dreidimensionalen Geländedarstellung in eine horizontale Ebene geschieht im einfachsten Fall 50 durch Nullsetzen der Höhenkoordinaten.

Zum Mustervergleich in der Rechnerstufe 62 zwischen der projizierten, zweidimensionalen Geländedarstellung und dem im Speicher 64 gespeicherten Geländeprofil wird zunächst zu Beginn der Navigations-Stützpunkt ein gesuchtes Muster, z. B. eine Straßenkreuzung wie Punkt "A" in Fig. 3, als ein Satz von Regeln zum Zusammensetzen des Musters aus elementaren Bildelementen wie Strichen und Winkeln kodiert. Dieser Satz von Regeln bildet eine Art "Konstruktions-Vorschrift" für das gesuchte Muster. Laßt sich aus den in der projizierten Geländedarstellung enthaltenen Bildelementen das gesuchte Muster, so wie es die Konstruktions-Vorschrift beschreibt, wiederfinden, so gilt das Muster als gefunden. Dieses Verfahren entspricht etwa dem Verfahren in der oben angeführten Literaturstelle "Agard Conference Proceedings" No. 474 (1990). Der Vorteil

dieses Verfahrens für das erste Suchen bei nur ungenauer Kenntnis von Lage, Orientierung und Größe des gesuchten Musters ist die weitgehende Toleranz gegenüber größeren Translations-, Rotations- und Maßstabsvariationen.

Wenn auf diese Weise ein Einstieg beim Mustervergleich zwischen aus dem Sensorbildern gewonnenen Geländedarstellung und gespeicherten Geländemodell (Landkarte) gefunden ist, kann die Lage weiterer, im Laufe des Fluges sichtbar werdender Objekte zunehmend genauer vorhergesagt werden. Die Suchbereiche werden klein. Maßstabs- und Rotationsabweichungen werden praktisch vernachlässigbar. Dann werden Musterkorrelations-Verfahren, wie sie oben im Zusammenhang mit den Mikromustern beschrieben wurden, angewandt.

#### Patentsprüche

1. Verfahren zur Stützung der Trägheitsnavigation eines als entferntes Ziel autonom ansiehenden Flugkörpers mittels eines unter einem endlichen Winkel seitwärts zur Flugrichtung blickenden, das überlagerte Gelände erfassenden, bilderzeugenden Sensors, der Geländedaten liefert, aus denen durch Vergleich mit bekannten Geländedaten eine Position des Flugkörpers gewonnen wird, wobei wiederum diese Position mit der von der Trägheitsnavigation bestimmten Position verglichen und das Trägheitsnavigationssystem nach Maßgabe dieses Vergleichs korrigiert wird dadurch gekennzeichnet, daß

(a) durch den bilderzeugenden Sensor während der Bewegung des Flugkörpers über dem Gelände aus verschiedenen Flugkörperpositionen laufend Bilder des überflogenen Geländes zur Erzeugung einer Bildsequenz aufgenommen werden,

(b) diese Bilder elektronisch gespeichert werden,

(c) aus gespeicherten Bildern und den zugehörigen, aus der Trägheitsnavigation erhaltenen Positionsdifferenzen des Flugkörpers durch Stereobild-Auswertung eine dreidimensionale Darstellung des Geländes berechnet wird,

(d) die berechnete Darstellung des Geländes mit einem gespeicherten Modell des Geländes verglichen und daraus die Position und der Kurs des Flugkörpers bestimmt wird.

2. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß durch den bilderzeugenden Sensor Folgen von Bildern in kurzen Zeitintervallen erzeugt und gespeichert werden und die dreidimensionale Darstellung des Geländes im Abstand der besagten Zeitintervalle jeweils aus Paaren von Bildern dieser Folge erzeugt werden, deren Aufnahmezeitpunkte sich um eine Mehrzahl von solchen Zeitintervallen unterscheiden.

3. Verfahren nach Anspruch 2, dadurch gekennzeichnet, daß in den Bildern des bilderzeugenden Sensors kontrastreiche Mikromuster laufend verfolgt und zur Berechnung der dreidimensionalen Darstellung der Stereobild-Auswertung unterworfen werden.

4. Verfahren nach Anspruch 3, dadurch gekennzeichnet, daß aus jedem Bild der Sequenz jeweils nur die kontrastreichen Mikromuster gespeichert

und verarbeitet werden.

5. Verfahren nach Anspruch 4, dadurch gekennzeichnet, daß

- ein Mikromuster in einem Bild der Sequenz gespeichert wird,
- in dem nächstfolgenden Bild das inzwischen durch die Bewegung des Flugkörpers im Gesichtsfeld des Sensors um einen Verschiebevektor verschobene Mikromuster durch ein Korrelations-Verfahren aufgesucht wird, und
- das so aufgesuchte verschobene Mikromuster zusammen mit Kenndaten des Mikromusters neu gespeichert wird.

6. Verfahren nach Anspruch 5, dadurch gekennzeichnet, daß die Kenndaten jedes Mikromusters nach Durchlaufen des gesamten Gesichtsfeldes des Sensors zur Berechnung der Lage des Mikromusters in einer dreidimensionalen Geländedarstellung ausgelesen werden.

7. Verfahren nach Anspruch 6, dadurch gekennzeichnet, daß die gespeicherten Kenndaten jedes Mikromusters wenigstens folgende Informationen umfassen:

- die laufenden Nummern der Bilder, in denen das Mikromuster erstmalig und letztmalig im Bild auftrat,
- den Verschiebevektor zwischen den Lagen des Mikromusters bei erstmaligem und letztmaligem Auftreten und
- den Grauwert eines zentralen Pixels des Mikromusters.

8. Verfahren nach einem der Ansprüche 5 bis 7, dadurch gekennzeichnet, daß die Mikromuster zeilenweise und in jeder Zeile parallel verarbeitet werden.

9. Verfahren nach Anspruch 8, dadurch gekennzeichnet, daß alle in einer Zeile auftretenden Mikromuster parallel verarbeitet werden.

10. Verfahren nach einem der Ansprüche 1 bis 9, dadurch gekennzeichnet, daß die dreidimensionale Darstellung des Geländes durch rechnerische Projektion der Darstellung auf eine horizontale Ebene in eine zweidimensionale Darstellung umgesetzt und mit einem gespeicherten zweidimensionalen Geländemodell verglichen wird.

11. Verfahren nach Anspruch 10, dadurch gekennzeichnet, daß

- zum Eintrag in die Positionstüzung zunächst markante Punkte des Geländes gesucht werden, die nach bestimmten Regeln aus elementaren Bildbestandteilen aufgebaut sind und
- nach Auffinden dieser Punkte und Positionstüzung durch Vergleich der gefundenen Punkte mit dem gespeicherten Geländemodell die weitere Positionstüzung durch ein Musterkorrelations-Verfahren erfolgt.

12. Vorrichtung zur Stützung der Trägheitsnavigation eines ein entferntes Ziel autonom ansteuernden Flugkörpers zur Durchführung des Verfahrens nach Anspruch 1, gekennzeichnet durch

- (a) einen unter einem endlichen Winkel seitwärts zur Flugrichtung blickenden, das überfliegene Gelände (10) erfassenden, bildzeugenden Sensor (36), durch den während der Bewegung des Flugkörpers über dem Gelände (10) aus verschiedenen Flugkörperpositionen (28, 30) laufend Bilder des überfliegenden Geländes

des (10) zur Erzeugung einer Bildsequenz aufgenommen sind,

(b) einen Speicher (68) zum elektronischen Speichern der von dem bildzeugenden Sensor (36) aufgenommenen Bilder,

(c) Rechnermittel mit Mitteln (58, 60) zum Berechnen einer dreidimensionalen Darstellung des Geländes (10) aus gespeicherten Bildern (32, 34) und den zugehörigen, aus der Trägheitsnavigation erhaltenen Positionsdifferenzen des Flugkörpers durch Stereobild-Auswertung,

(d) Mittel zum Speichern eines dreidimensionalen Modells des überfliegenden Geländes (10),

(e) Mittel (52) zum Vergleichen der berechneten dreidimensionalen Darstellung der Landschaft mit dem gespeicherten Modell der Landschaft (10) und

(f) Mittel (66) zum Bestimmen der Position und des Kurses des Flugkörpers aus dem Vergleich der berechneten Darstellung des Geländes und des gespeicherten Modells dieses Geländes.

13. Vorrichtung nach Anspruch 5, dadurch gekennzeichnet, daß die Rechnermittel eine Parallelrechner-Struktur (70, 72) enthalten.

Hierzu 4 Seite(n) Zeichnungen

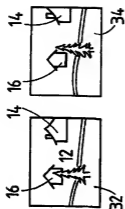


Fig. 2

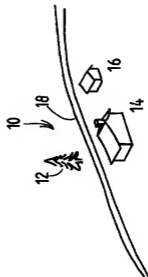
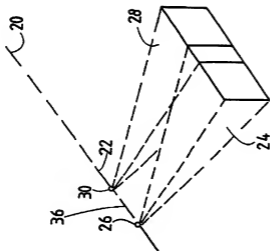
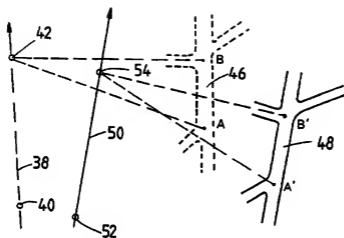


Fig. 1





**Fig. 3**

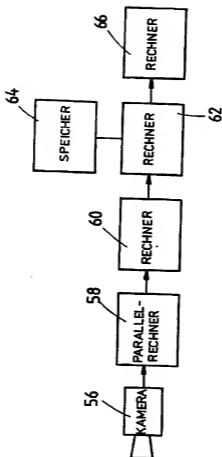


Fig. 4

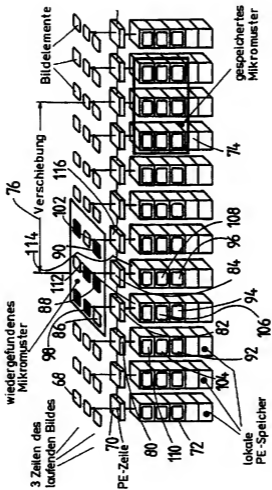


Fig. 5

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H4D DLAS D714 D733 D753  
U1B S1187

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GB 2108347 A EP 0381178 A1 EP 0157414 A2  
EP 8118324 A1 EP 0095080 A2 US 4514723 A

(58) Field of Search

UK CL (Edition N) G11F F10, H4D DLAA DLAS DLPC  
DLPG DLPX DLNP  
INT CL<sup>6</sup> F41G, F42B, G01S, G05D

(54) Missile location

(57) A method for updating the inertial navigation of a missile autonomously heading for a remote target uses an image generating sensor looking downwards and sideways to cover the terrain flown over. Pictures are continuously taken by the image generating sensor during the movement of the missile over the terrain from different missile positions to generate a picture sequence. These pictures are stored electronically. From the stored pictures and the associated position differences of the missile provided by an inertial navigation system, a three-dimensional representation of the terrain is computed by stereo-picture evaluation. The computed representation of the terrain is compared with a stored model of the terrain, and the position and heading of the missile is determined therefrom.

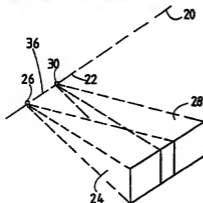


Fig. 1

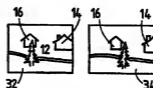


Fig. 2



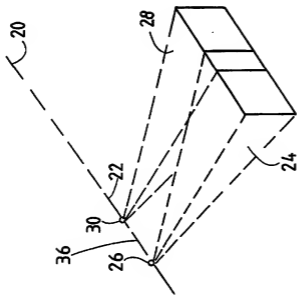


Fig. 1

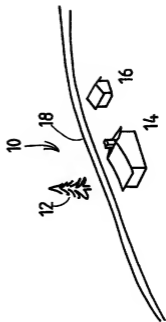
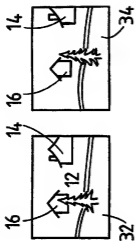


Fig. 2



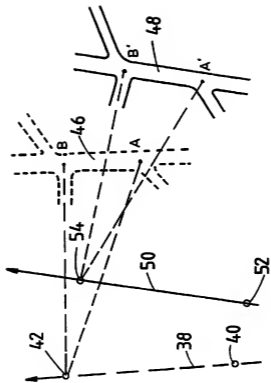


Fig. 3

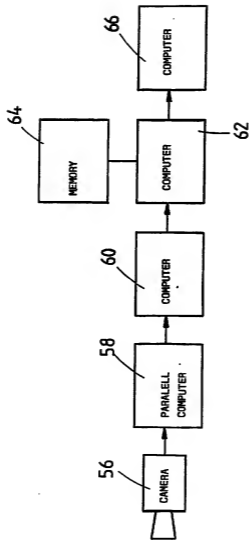


Fig. 4

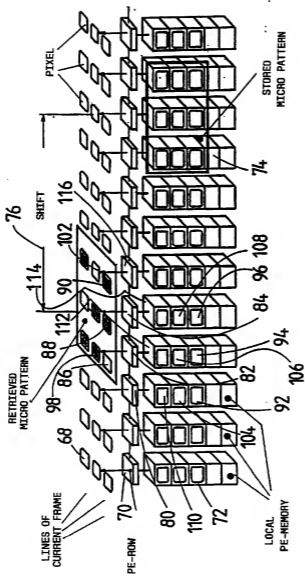


Fig. 5

Method and Device of Updating the Inertial Navigation of a  
Missile Autonomously Heading for a Remote Target

**Technical Field**

The invention relates to a method of updating the inertial navigation of a missile heading for a remote target by means of an image-generating sensor looking sideways to the flight direction and detecting the terrain flown-over, the sensor providing terrain data by comparison of which with known terrain data a position of the missile is obtained, this position, in turn, being compared with the position determined by the inertial navigation, the inertial navigation system being corrected in accordance with this this comparison.

Furthermore, the invention relates to a device for updating the inertial navigation of a missile autonomously heading for a remote target, such device carrying out the aforementioned method.

**Background Art**

Low-flying autonomous missiles are, for example, the so-called "cruise missiles". The navigation of such missiles is based primarily on inertial navigation. An inertial sensor unit constructed with gyros and accelerometers provides data about position, velocity and heading of the missile. Such inertial sensor units are subjected to drift. The indicated position and the heading of the missile change slowly. The errors become the larger the longer the

flight time continues. It is therefore necessary to check position and heading of the missile from time to time and to effect corrections of the inertial sensor unit.

5 It is possible to update the position by receiving and processing signals from navigation satellites (GPS). The position determination based thereon ensures high precision. With military equipment, however, it is often required that the navigation is absolutely autonomous.

10 Furthermore, it is known to scan the terrain flown-over by means of a RADAR set provided on-board the missile. But this type of position check does not meet the requirement of absolute passivity, thus of the interdiction of the  
15 emission of telltale active radiation.

20 Furthermore, it is known to take snapshot-like individual pictures of the terrain flown-over by means of a passive, image-generating sensor. If at least three known and identified objects are in the picture simultaneously, both the position and the orientation of the sensor at the moment of taking the picture can be computed from the angles between these objects appearing in the picture and the angles relative to the direction of view of the sensor  
25 by applying a three-dimensional "three-point problem". If the image generating sensor detects less than three objects, it is possible to include the flight path between taking of two individual pictures into the computation, the flight path being determined by means of the inertial  
30 sensor unit (R.Koch, R.Bader, W.Hinding: "A Study of an Integrated Image and Inertial Sensor System" in "Agard Conference Proceedings" No 474 (1990)).

35 The applicability of this procedure depends on sufficiently many identified objects being available in the terrain. The

errors of the measurement largely depend on the position of these objects relative to the missile. The requirement of unambiguous identification necessitates an expensive recognition process. Depending on the direction of view, it may be impossible to compare, for the purpose of identifying the object, the image contents directly with a stored model of the object. Rather is it necessary, with oblique direction of view, to make a quantitative comparison of the expected object with the seen object through a perspective transformation of the terrain model stored in the missile into the image plane. Only with the aid of this comparison, the position and the heading can be determined and, if necessary, corrected.

Between the updating objects, the missile has to navigate "blind" with the inertial navigation only. If the updating objects are located close to one another, confusion of objects having similar appearance may occur due to positional deviations caused by drift. If one updating object fails to show up, the positional deviation may become so large that the next but one updating object cannot be found any longer.

DE-A-3,412,533 describes an image generating sensor for three-dimensional covering of scene, in particular for use in industrial automation. A sequence of pictures is taken from different directions. Pairs of pictures are generated, from which a stereoscopic picture of the covered scene can be obtained. Image processing is effected by means of a parallel-processing, digital network for making quick correlation comparisons of image sections.

EP-A-0,122,048 describes a parallelly-operating data processor.

# Disclosure of the Invention

It is the object of the invention to provide a method of the type mentioned in the beginning for the updating of the inertial navigation of a missile autonomously heading for a remote target, wherein

- the information provided by the image generating sensor about the terrain flown-over is optimally utilized,
- the updating of the inertial navigation by this information is effected quasi-continuously, and
- the updating is independent of the presence of prominent updating objects in the terrain flown-over.

According to the invention this object is achieved with a method of the type mentioned in the beginning in that

- (a) the image generating sensor, during the movement of the missile over the terrain, continuously takes pictures of the terrain flown-over from different missile positions,
- (b) these pictures are stored electronically,
- (c) a three-dimensional representation of the terrain is computed by stereo-picture evaluation from stored pictures and the associated position differences of the missile derived from the inertial navigation,
- (d) the computed representation of the terrain is compared with a stored model of the terrain, and the position and the heading of the missile is determined therefrom.

A device for the carrying out of the method is characterized by

5 (a) an image generating sensor looking sideways to the flight direction at a finite angle and covering the terrain flown-over, this sensor being arranged to take pictures of the terrain flown-over from different missile positions, while the missile moves over the  
10 terrain, to generate a picture sequence,

(b) a memory for electronically storing the pictures taken by the image generating sensor,

15 (c) computer means with means for computing by stereo-picture evaluation a three-dimensional representation of the terrain from stored pictures and the associated position differences of the missile derived from the inertial navigation,  
20

(d) means for storing a three-dimensional model of the terrain flown-over,

25 (e) means for comparing the computed three-dimensional representation of the landscape with the stored three-dimensional model of the landscape, and

30 (f) means for determining the position and heading of the missile from the comparison of the computed representation of the terrain and the stored model of this terrain.

Modifications of the invention are subject matter of the sub-claims.

An embodiment of the invention is described in greater detail hereinbelow with reference to the accompanying drawings.

- 5     Fig.1     is a schematic-perspective representation and shows, how a terrain is observed consecutively from two positions of a missile by means of an image generating sensor attached to the missile.
- 10    Fig.2     shows the image contents covered by the image generating sensor in the two positions.
- 15    Fig.3     illustrates the determination of position by pattern comparison of the observed terrain with a stored terrain.
- 20    Fig.4     is a block diagram and illustrates a device for the updating of the inertial navigation of a missile heading for a remote target by means of an image generating sensor looking sideways to the flight direction at a finite angle and covering the landscape flown-over.
- 25    Fig.5     is a schematic representation and illustrates the image processing of micro-patterns in the picture of the terrain by means of a parallel computer.

#### Preferred Embodiment of the Invention

- 30    Referring to Fig.1, numeral 10 designates a terrain, which is schematically indicated by a tree 12, two houses 14 and 16 and a path 18 passing therebetween. A missile flies with a heading 20 along a trajectory 22. The missile has an image generating sensor in the form of a video camera. The
- 35    image generating sensor "looks" sideways to the flight

direction of the missile at a finite angle. The sensor covers, in each position, a field of view of rectangular cross section. Fig.1 shows the field of view 24 of the sensor for a first position 26 of the missile and the field of view 28 of the sensor for a second position 30.

In the positions 26 and 30, the sensor provides pictures 30 and 32, respectively, of the terrain 10. In picture 32 of Fig.2, the tree is arranged in front of the house 16. In picture 34 of Fig.2, the tree 12 is visible between the houses 16 and 14. A stereoscopic representation of the terrain 10 can be computed from the two pictures 32 and 34. The stereo-basis is the distance 36 between the two positions 26 and 30. This distance can be provided by the inertial sensor unit of the missile. The error of the stereo-basis is, at a rule, small, if the pictures are taken at not too large time intervals. A three-dimensional representation of the terrain flown-over results. This three-dimensional representation of the terrain flown-over is compared with a stored model of the terrain. The deviation of the position provided by the inertial navigation and of the heading provided by the inertial navigation from the actual position and the actual heading, respectively, can be determined by a correlation computation. The output of the inertial sensor unit can be corrected and updated correspondingly.

This is schematically illustrated in Fig.3. Referring to Fig.3, numeral 38 designates a trajectory of the missile, as resulting from the inertial navigation. Accordingly, the missile would be at a position 40 at a moment  $t_0$  and at a position 40 at a moment  $t_1$ , corresponding to the positions 26 and 30 in Fig.1. In its field of view corresponding to the field of view 28 of Fig.1, the sensor observes a terrain which, in Fig.3, is illustrated as a road 46 with

junctions. The trajectory 38 (in a map) indicated by the inertial navigation and the observed road, the position of which in the map is referenced to this trajectory 38, are illustrated in dashed lines in Fig.3. In the stored "map", the road is actually located at the position 48. The trajectory 38 provided by the inertial navigation has to be corrected to provide a "true" trajectory 50 with the positions 52 at the moment  $t_0$  and 54 at the moment  $t_1$ , which is located with respect to the road 48 stored in the map in the same way as the trajectory 38 is located with respect to the road 46 shown in dashed lines.

This can be done in the following way:

Small windows, which are characterized by clear contrasts, are considered in the three-dimensional representation of the terrain. It be assumed that these are the areas around the points A and B in Fig.3. A correlation function with the stored model of the landscape (map) is computed for these windows. Practically, the window is shifted relative to the map until optimal conformity has been reached and the correlation function has a maximum. In this way, the points A' and B' on the map are determined which correspond to the contrast-rich windows around the points A and B, respectively, which are observed by the sensor. No recognition of objects is required for this. Within the range of the relatively small windows, distortion of the representation of the terrain due to inaccuracies of the stereo-basis are less critical, as this would be the case, if the correlation function had been formed over the whole picture contents. The computing expenditure and the required memory capacity are considerably reduced as compared to the latter alternative.

The position of the points A and B relative to the position 42 affected by errors is known. From the computation of the three-dimensional terrain structure, the distances of the position 42 from the points A and B of the observed terrain can be derived. From the now known points A' and B' on the map, determined with the aid of the correlation function, it is now possible to determine the point 54 on the map, i.e. the true position. The true position 54 is located exactly in the same relative position with respect to the "map-fixed" points A' and B', as the position 42 provided by the inertial navigation with respect to the points A and B in the observed terrain.

When the position of the missile has been determined in the manner described, and the inertial navigation unit has been updated correspondingly, the further movement of the picture points are tracked quasi-continuously. Picture points are defined by small, high-contrast "micro-patterns" of, for example, 3 x 3 pixels. In each picture, a correlation function is formed or a direct comparison is made to ascertain, to which location a "micro-pattern" observed in the preceding picture has moved. To this end it is only necessary to consider in each picture only the near surroundings of that spot at which the respective micro-pattern has been located in the preceding picture. Provision can be made that the picture points move substantially in the direction of the rows of the picture raster of the image generating sensor. There will be displacement vectors for each considered micro-pattern, which represent the movement of the respective micro-pattern over the field of view covered by the sensor. During this procedure, new micro-patterns continuously enter the field of view at the front edge of the field of view, a number of such micro-patterns being selected and the movements of such selected micro-patterns being tracked and

stored. Micro-patterns leave the field of view at its rear edge.

5 A three-dimensional representation of the terrain, as far as it is represented by the micro-patterns, is computed from the positions of the micro-patterns in pairs of different pictures, which are separated by a time interval during which the missile has traversed one stereo-basis. As the micro-patterns are continuously tracked during their  
10 passage through the field of view of the sensor, their positions in each of the pictures of the sequence is known. Therefore, it is not necessary to recover micro-patterns in pictures, which are taken at substantially different times. The three-dimensional representation of the terrain is  
15 computed as follows: When a micro-pattern enters the field of view of the sensor at the front edge thereof, the running number of the associated picture of the sequence is stored and, thereby, the time, when this micro-pattern enters the field of view of the sensor. In the consecutive  
20 pictures of the sequence, the micro-pattern travels through the field of view and, eventually, leaves the field of view at its opposite rear edge. The running number of the associated picture is also stored and, thereby, the time, when the micro-pattern leaves the field of view. The  
25 stereo-basis is obtained from the time difference and the velocity of the missile. Thereby, the location of the micro-pattern can be computed three-dimensionally. The same procedure is applied to all considered micro-patterns travelling through the field of view. Thereby, a three-  
30 dimensional representation of the terrain scanned by the field of view of the sensor is continuously obtained.

On the basis of the micro-patterns, high-contrast windows in the observed terrain, which are used for the updating of  
35 the inertial navigation, can be continuously tracked from

picture to picture. The quasi-continuously computed three-dimensional representation of the terrain in the window is continuously compared with a stored terrain pattern. Therefrom, the true position of the missile can be  
5 continuously determined by forming a correlation function over the window between this representation of the terrain and the terrain model, as has been described above. In this procedure, the computation of the three-dimensional representation of the terrain and the correction of the  
10 position provided by the inertial navigation alternate continuously. Thereby, the trajectory indicated by the inertial navigation deviates only slightly from the true trajectory. Correspondingly, the computation of the correlation function for the determination of the deviation  
15 can confine itself to the immediate neighborhood of the window fixed in the field of view of the sensor.

The continuous updating of the comparison between the presently observed terrain and the on-board terrain model  
20 (map) permits also the inclusion of picture contents, which as small individual objects would be difficult to identify. The terrain model permits prediction of what can be observed by the sensor in the picture, as the position of the window in the terrain pattern is, to a large extent,  
25 known. It is then possible to "search" and also process such picture contents. This permits utilization of picture details which are little characteristic and, by themselves, would not yet permit a position information to be derived therefrom. Thereby redundancy is achieved, which is  
30 required, in particular, in little-structured terrain.

Fig.4 shows, as a block diagram, a device for the carrying-out of the described method.

Referring to Fig.4, numeral 56 designates an image generating sensor. The image generating sensor is a video camera. The sensor 56 supplies pictures to a parallel computer 58. The parallel computer 58 compares the micro-patterns with the required high processing speed. The parallel computer 58 provides for each micro-pattern, which is observed during its travel through a plurality of pictures, the length of the displacement vector of the micro-pattern and the picture numbers of the first and last pictures in which this micro-pattern was observed.

A following computer stage 60 is composed of standard computer devices, such as the conventional signal processors. The computer stage 60 receives the flight velocity vector from the inertial sensor unit and the flight time between that picture of the sequence of pictures of the sensor 56, in which a considered micro-pattern occurs for the first time, and that picture, in which the micro-pattern reaches the rear edge of the field of view. The stereo-basis is computed from the time difference between the pictures and the flight velocity vector. Therewith, the location of the terrain portion represented by the micropattern is computed by triangulation. Furthermore, the computer stage causes projection of the three-dimensional terrain representation obtained from the various micro-patterns on a horizontal plane. Thereby, a two-dimensional terrain representation similar to a map is obtained for comparison with an also two-dimensional, map-like terrain model, which is stored in the missile.

A third computer stage 62 effects comparison of the terrain representation derived from the pictures of the sensor 56 in the described manner with a terrain pattern, which is stored in a memory 64. The computer stage provides the

shifting of the terrain representation derived from the pictures of the sensor 56 (in the coordinate system of the terrain model) relative to the terrain model. A navigation computer 66 determines therefrom, in a manner described with reference to Fig.3, the true position and the true heading of the missile in the terrain pattern (the map). From the deviations of position and heading of the missile, correction values for the inertial sensor unit are derived.

Fig.5 illustrates the image processing of micro-patterns in the picture of the terrain by means of the parallel computer 58.

In the schematic illustration of Fig.5, numeral 68 designates memory elements in which picture elements of the picture covered by the sensor 56 are stored. Fig.5 shows three rows of such memory elements 68, in which the picture elements of three rows of the picture are stored. The parallel computer 58, which represents the first computer stage, contains a one-dimensional array of processor elements 70. A local memory 72 having a plurality of memory cells is associated with each processor element 70.

Out of the picture elements (pixels) of a  $(n-1)$ th picture, a micro-pattern 74 of  $3 \times 3$  pixels is stored at its location in the  $(n-1)$ th picture. To this end, the  $(n-1)$ th picture has been scanned row by row by the processor element 70. The pixels of the various rows are filed in the memory elements in the various planes of the local memory, thus "one below the other" in Fig.5.

In the  $n$ -th picture, the same micro-pattern, due to the movement of the sensor 56, appears as micro-pattern 74A at a different location of the picture, namely further to the left in Fig.5. The shift is to be determined. This is done

by means of a correlation method. In order to determine the length of the shift vector of the micro-pattern 74 from picture to picture, the amounts of differences for all nine pixels of the micro-pattern and of a micro-pattern to be compared therewith are formed and summed up:

$$K = \sum |\text{Pixel}(B_n) - \text{Pixel}(B_{n-1})|.$$

This provides a measure of the degree of conformity of 3x3-micro-patterns. If it is assumed, that the flight direction of the missile is exactly parallel to the rows of the pictures, then the micro-pattern 74 needs only be shifted within the rows to the left in Fig.5, until the value of K becomes a minimum. The minimum of a correlation function

$$K(\Theta) = \sum |\text{Pixel}_n(x-\Theta, y) - \text{Pixel}_{n-1}(x, y)|$$

with  $\Theta$  as shift coordinate is determined. The position of the minimum is designated by  $\Theta_{\min}$ . The sum is again taken over all nine pixels surrounding the original position and the sought position. If  $\Theta$  is counted from the position of the micro-pattern in the (n-1)th picture,  $\Theta_{\min}$  is the length of the shift vector 76 for the respective micro-pattern between two pictures.  $K(\Theta_{\min})$  is a measure of the quality of the conformity. The conformity is the better, the smaller  $K(\Theta_{\min})$  is.

In detail, the procedure is as follows: The n-th picture is processed row by row. At first, the three pixel 86, 88 and 90 of the first row of the micro-pattern are compared with the pixels which have been stored from the (n-1)th picture in the memory elements 92, 94 and 96. The processor elements 80, 82 and 84 form the differences of the pixel contents. The amounts of these differences are added and

are stored in a memory element of the local memory of the central processor element 82. Then, in the same way, the pixels 98, 100, 102 of the second row of the micro-pattern 74A are compared with the pixels, which have been stored from the (n-1)th picture in the memory elements 104, 106 and 108 of the local memories of the processor elements 80, 82 and 84, respectively. Again the differences of the pixel contents are formed. The amounts of these differences are added and are added to the difference sum stored in the local memory of the central processor element. The same happens with the three pixels of the third row of the micro-pattern 74A and the pixels stored in the memory elements 110, 112 and 114. Also here, the differences of the pixel contents and the sum of the amounts of these differences are formed and again added to the difference sum stored in the local memory of the processor element 82 from the other two rows. Therefore, the correlation function of the micro-pattern 74A of the picture (n-1) with the micro-pattern stored "therebelow" from picture n is stored in the local memory of the central processor element 82, "central" with respect to the micro-pattern 74A.

Subsequently, the micro-pattern 74 is "shifted by one step", i.e. it is compared in the same way with the 3x3-micro-patterns stored in the local memories of the processor elements 82, 84 and 116, and the correlation function is formed. This proceeds step-by-step, until the comparison with the micro-pattern 74 is effected. The micro-patterns 74 and 74A are identical. The correlation function becomes a minimum, ideally zero. Thereby, the micro-pattern 74 of the (n-1)th picture has been "retrieved" in the micro-pattern 74A of the n-th picture. The number of the steps required herefor, the variable  $\Theta$ , yields the shift vector 76, by which the micro-pattern 74 has been shifted in the field of view of the sensor 56 in the time interval from

the  $(n-1)$ th picture to the  $n$ -th picture. In the present case, this shift vector extends in the direction of the rows. The amount of the shift vector is added to the sum of the previously determined shift vectors of the respective micro-pattern. The latter sum had been stored in the local memory of the central processor element at the location of the micro-pattern 74. The new sum is stored in the local memory of the processor element 82. The micro-pattern 74A is stored in the local memories of the processor elements 80, 82 and 84. The micro-pattern 74 is erased.

Now the same operation is repeated with the  $(n+1)$ th picture and the  $n$ -th picture. This procedure is repeated with the sequence of the pictures.

The procedure described can be carried out in parallel by all processor elements of the row for all valid micro-patterns. Only three rows of the current picture are illustrated in Fig.5. Actually, the picture has substantially more rows. These rows are processed with the micro-patterns contained therein consecutively in the described manner by means of the processor elements 70.

For the adding of new micro-patterns from younger pictures, an admission test for micro-patterns is required. Not every  $3 \times 3$  matrix of the picture can and should be processed in the manner described. There are homogeneous and -as compared to the picture noise- little-structured areas in the picture, with which the described procedure would fail. Therefore, only those  $3 \times 3$ -areas are admitted as valid micro-patterns, which have a predetermined minimum remarkability, whereby sufficiently marked minima of the correlation function not falsified by picture noise can be expected. A criterion herefor is a variance measure.

In this way, the micro-pattern travels across the field of view of the sensor 56. The stored characteristic data of those micro-patterns which have reached the rear edge of the field of view are read out. These characteristic data include the time interval required for the total travel of the micro-pattern, the length of the total distance travelled by the micro-pattern and, at least, the picture half-tone of the central pixel. The time interval required for the total travel is the time difference between the first appearance of the micro-pattern and its last shifting step. This time interval is obtained from the difference of the associated picture numbers divided by the picture frequency. The length of the total distance of shift results from the difference of the column addresses of the first and last positions of the micro-patterns. In order to determine this distance with an accuracy of fractions of pixels, it is possible to carry out a ,for example, parabolic interpolation between the three measured values of the correlation function surrounding the theoretical minimum of the correlation function. The characteristic data are forwarded to the computer stage 60.

The respective stereo-basis can be determined from the characteristic data. Simple triangulation yields the location of the object detail represented by the micro-pattern.

The projection of the so obtained three-dimensional terrain representation into a horizontal plane, which is to be carried out at the end, is effected, in the simplest case, by setting the altitude coordinate to zero.

In order to compare, in the computer stage 62, patterns of the projected, two-dimensional terrain representation and the terrain profile stored in the memory 62, at first, at

the beginning of the navigation updating, a searched pattern such as the road intersection "A" in Fig.3 is encoded as a set of rules for composing the pattern from elementary picture elements like lines and angles. This set of rules represents a kind of "design direction" of the searched pattern. If from the picture elements contained in the projected terrain representation the searched pattern as described in the design direction can be retrieved, the pattern is regarded as found. This procedure is substantially identical with the procedure in the above mentioned paper "Agard Conference Proceedings" No 474 (1990). The advantage of this procedure for the first search with only inaccurate knowledge of position, Orientation and size of the searched pattern is the far-reaching tolerance with respect to rather large translational, rotational and scale variations.

If in this way access to the pattern comparison between the terrain representation obtained from the sensor pictures and the stored terrain model (map) has been gained, the position of further objects becoming visible in the course of the flight can be predicted with progressive accuracy. The search areas become small. Scale and rotational deviations become virtually negligible. Then pattern correlation methods as described above with reference to the micro-patterns are used.

## Claims

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1. A method of updating the inertial navigation of a missile heading for a remote target by means of an image-generating sensor looking sideways to the flight direction and detecting the terrain flown-over, the sensor providing terrain data by comparison of which with known terrain data a position of the missile is obtained, this position, in turn, being compared with the position determined by the inertial navigation, the inertial navigation system being corrected in accordance with this this comparison,

wherein:

- (a) the image generating sensor, during the movement of the missile over the terrain, continuously takes pictures of the terrain flown-over from different missile positions,
- (b) these pictures are stored electronically,
- (c) a three-dimensional representation of the terrain is computed by stereo-picture evaluation from stored pictures and the associated position differences of the missile derived from the inertial navigation,
- (d) the computed representation of the terrain is compared with a stored model of the terrain, and

the position and the heading of the missile is determined therefrom.

2. A method as claimed in claim 1, wherein  
5 sequences of pictures are generated, at short time intervals, by the image generating sensor and are stored, and the three-dimensional representations of the terrain are generated, at these time intervals, from respective pairs of pictures of this sequence, the  
10 moments of taking the pictures of each pair differing by a plurality of such time intervals.

3. A method as claimed in claim 2, wherein  
15 high-contrast micro-patterns in the pictures of the image generating sensor are continuously tracked and are subjected to the stereo-picture evaluation to compute the three-dimensional representation.

4. A method as claimed in claim 2, wherein  
20 only the high-contrast micro-patterns from each picture of the sequence are stored and processed.

5. A method as claimed in claim 4, wherein

- 25 - a micro-pattern in one picture of the sequence is stored,
- 30 - in the next-following picture, the micro-pattern shifted by a shift vector in the field of view of the sensor in the meantime due to the movement of the missile is searched by a correlation method, and

- the shifted micro-pattern thus searched is stored anew together with characteristic data of the micro-pattern.

5 6. A method as claimed in claim 5, wherein  
the characteristic data of each micro-pattern are read  
out, after the micro-pattern has travelled across the  
whole field of view of the sensor for the computation  
of the position of the micro-pattern in a three-  
10 dimensional representation of the terrain.

7. A method as claimed in claim 6, wherein  
the stored characteristic data of each micro-pattern  
include, at least, the following information:

- the running number of the pictures, in which the  
micro-pattern appeared for the first time and for  
the last time,

- the shift vector between the positions of the  
micro-pattern at its appearance for the first time  
and at its appearance for the last time, and

- the picture half-tone of a central pixel of the  
micro-pattern.

8. A method as claimed in anyone of the claims 5 to 7,  
wherein the micro-patterns are processed  
row-by-row and in parallel in each row.

9. A method as claimed in claim 8, wherein  
all micro-patterns appearing in one row are processed  
in parallel.

10. A method as claimed in anyone of the claims 1 to 9,  
wherein the three-dimensional  
representation of the terrain is converted to a two-  
dimensional representation by projecting the  
representation on a plane by computation, and the two-  
dimensional representation is compared with a stored  
two-dimensional terrain model.

11. A method as claimed in claim 10, wherein

- in order to gain access to the position updating,  
marked points of the terrain are, at first,  
selected, which are structured out of elementary  
picture components in accordance with particular  
rules, and

- after these points have been found and the position  
has been updated by comparison of the found points  
with the stored terrain pattern, the further  
position updating is effected by a pattern  
correlation method.

12. A device for the updating of the inertial navigation of  
a missile autonomously heading for a remote target, for  
carrying out the method of claim 1, wherein

(a) an image generating sensor looking sideways  
to the flight direction at a finite angle and  
covering the terrain flown-over, this sensor  
being arranged to take pictures of the terrain  
flown-over from different missile positions,  
while the missile moves over the terrain  
to generate a picture sequence,

(b) a memory for electronically storing the pictures taken by the image generating sensor

5 (c) computer means with means for computing by stereo-picture evaluation a three-dimensional representation of the terrain from stored pictures and the associated position differences of the missile derived from the inertial navigation,

10 (d) means for storing a three-dimensional model of the terrain flown-over,

15 (e) means for comparing the computed three-dimensional representation of the landscape with the stored three-dimensional model of the landscape, and

20 (f) means for determining the position and heading of the missile from the comparison of the computed representation of the terrain and the stored model of this terrain.

25 13. A device as claimed in claim 5, wherein the computer means have a parallel computer structure.

14. A method of updating the inertial navigation of a missile heading for a remote target substantially as described hereinbefore with reference to the accompanying drawings.

15. A device for carrying out the method according to claim 14 substantially as described hereinbefore with reference to the accompanying drawings and as shown in Figure 4, or in Figure 4 and Figure 5.



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UK Patent Office collections, including GB, EP, WO & US patent specifications, in:  
UK Cl (Ed.N): H4D (DLAA, DLAB, DLPD, DLPC, DLRP, DLPX); G1F (F10)  
Int Cl (Ed.6): G05D; G01S; F42B; F41G  
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**Documents considered to be relevant:**

Category	Identity of document and relevant passage	Relevant to claims
Y	GB2108347A Diehl - whole document	1,12 at least
Y	EP0381178A1 Honeywell - whole document	1,12 at least
Y	EP0157414A2 Honeywell - whole document	1,12 at least
Y	EP0118324A1 Thomson CSF - whole document	1,12 at least
Y	EP0095660A2 MBB - whole document	1,12 at least
Y	US4514733 Vereinigte Flugtechnische Werke GMBH - whole document	1,12 at least

X Document indicating lack of novelty or inventive step  
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A Document indicating technological background and/or state of the art.  
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(54) Title: METHOD FOR PRODUCING STEREOSCOPIC IMAGES FROM MONOSCOPIC IMAGES

(57) Abstract: The invention provides a method for producing a series of stereoscopic pairs of images that can be displayed one after the other as a stereoscopic movie. The sequence of stereoscopic pairs is derived from a sequence of consecutive images of a scene that is obtained by standard techniques using standard equipment. A first image of a pair of images comprising the right and left images of each frame of the stereoscopic series of images is selected from the original sequence of images. Its stereo partner is either selected from the original sequence and/or is generated by transforming images selected from the original sequence of images.

## METHOD FOR PRODUCING STEREOSCOPIC IMAGES FROM MONOSCOPIC IMAGES

Field of the Invention

The present invention relates to the field of stereoscopic series of images. More specifically the invention relates to a process for producing stereoscopic series of images from a series of consecutive two-dimensional images of a scene, the images being acquired with a standard non-stabilized camera.

BACKGROUND of the Invention

Stereoscopic, or three-dimensional, photography is based on the principle of human vision. Two separate detectors (the eyes) detect the same object from slightly different angles and project them onto two planes (the retinas). The resulting images are transferred to a processor (the brain) which combines them and gives the perception of the third dimension, i.e. depth, to the scene.

Since the first practical demonstration of a stereoscope by Wheatstone in 1838, many different methods of creating and displaying stereo images have been developed. Most are hardware based methods such as using two cameras with a fixed relation between them or a single camera with two lenses to photograph a scene and produce the two slightly shifted images needed.

Similarly, many methods of viewing the stereoscopic images have been developed and include the use of colored or polarizing filters to separate the two images, temporal selection by successive transmission of the images using a shutter arrangement, or physical separation of the images in the viewer and projecting them separately to each eye. The last method was, on the one hand, the one originally used by Wheatstone and, on the other hand, employed in the latest virtual reality techniques.

The above mentioned methods of producing and viewing stereoscopic images and are well known in the art and need not be described in further detail herein.

Stereoscopic series of images are, in principle, nothing but a series of stereoscopic images that are viewed in succession. They are usually produced by means of series of images cameras with two slightly displaced lenses that record pairs of frames of images. Each frame shows the scene at a slightly different angle than its partner. In order to obtain a film in which the viewed action appears to flow continuously and naturally, the utmost stability is required during the photographing process. As a result, to date prior art stereoscopic series of images have been produced only by use of specially designed and stabilized cameras.

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Methods of producing a seamless stereo pair of mosaics from a moving video camera have been developed by, for example, Peleg, *et. al.* [WO 00/39995] and Zhu, *et.al.* [ Parallel-Perspective Stereo Mosaics, IECC International Conference on Computer Vision, Vancouver, Canada, July 2001, Vol.1 pp.345-352]. In order to produce three dimensional effects, according to these methods, matches are performed on the stereo mosaics and not on the individual video frames. These methods essentially take a video film and turn it into a static mosaic. The resulting views are static and don't give the viewer the feeling of motion of the camera that was contained in the original film.

To date, no method has been proposed to produce stereoscopic series of images from a video film produced by a hand held video camera. Also, in none of the existing methods is it possible to record an audio track together with the original series of images and to reproduce it with the resultant stereo images.

It is therefore a purpose of the present invention to provide a method of producing a stereoscopic movie from any series of consecutive images of a scene in which the conditions of parallax necessary for human vision exist.

It is another purpose of this invention to provide a method of producing stereoscopic movie from a series of consecutive images of a scene, the images

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being acquired without the use of specialized cameras, tripods, or stabilizing equipment.

Further purposes and advantages of the invention will appear as the description proceeds.

### Summary of the Invention

The present invention is directed to providing a method for taking a sequence of consecutive images of a scene and producing from these images a series of stereoscopic pairs that can be displayed one after the other as a stereoscopic movie. The sequence of images is obtained by standard techniques using standard equipment. The sequence of images can comprise frames taken with a video camera or a digital still camera, or analog images that are scanned to produce the digitized images. The analog images can be images taken with a still or movie camera. The pair of images comprising the right and left images of each frame of the stereoscopic series of images are either selected from the original sequence of images and/or generated by transforming images selected from the original sequence of images.

According to a preferred embodiment of the invention, the method of producing the sequence of stereo pairs comprises the following steps:

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- a) reading the original sequence of consecutive images of a scene with a device that is capable of digitizing the images, if necessary;
- b) storing the digitized images in a memory unit;
- c) selecting a subset of images of interest;
- d) computing the collection of affine transformations between the images in the subset;
- e) selecting one image of the sequence of the subset of images of a scene that will be one member of the first stereo pair of the sequence;
- f) searching for a suitable stereo partner for said selected image by determining the cascaded affine transformation to each of the successive images starting with the neighboring image to said selected image and applying the parallax criterion until a suitable stereo partner, i.e. an image that can be transformed into the second member of said stereo pair is found;
- g) calculating a planar transformation by using the members of said stereo pair and the cascaded affine transformation between the members of said pair;
- h) applying said planar transformation to said suitable stereo partner;
- i) storing said stereo pair in the memory unit; and

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- j) repeating steps e) through h) for the next and each of the remaining images of said selected subset.

The parallax criterion is the number of pixels of horizontal translational motion between the image centers of the selected image and the image being considered as a possible stereo partner. The search in the original series of images for a suitable stereo partner for a selected image of the series is carried out amongst the neighboring images on both sides of the selected image and is limited to a predetermined maximum number of images on either side of the selected image.

A stereoscopic movie produced by the method of the invention can be accompanied by a sound track, which is essentially identical to the sound track recorded with the sequence of consecutive images.

All the above and other characteristics and advantages of the invention will be further understood through the following illustrative and non-limitative description of preferred embodiments thereof, with reference to the appended drawings.

#### **Brief Description of the Drawings**

- Fig. 1 shows a portion of the scene which the photographer records as he walks at a uniform rate;

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- Fig. 2 shows schematically how the scene of Fig. 1 would appear on the film;
- Figs. 3A to 3F schematically show the information about the small house that is contained in each of the frames of Fig. 2;
- Fig. 4A schematically shows the intersection of the line-of-sight of the camera with the scene being photographed for the more realistic case;
- Fig. 4B schematically shows six consecutive frames of a video film illustrating the effect of motion of the lens;
- Fig. 5 is a series of images taken from consecutive frames of a video film taken with a hand-held commercial video camera;
- Fig. 6 shows the results of applying the method of the invention to one of the images shown in Fig. 5; and
- Fig. 7 shows the stereo pairs for each of the images of Fig. 5.

### **Detailed Description of Preferred Embodiments**

Definition: In this application, the terms "sequence of stereoscopic images" and "stereoscopic movie" are used interchangeably to mean a motion picture that represents the scene as recorded by the camera.

The purpose of the invention is to take a continuous sequence of digitized images of a scene and to produce from these images a series of stereoscopic pairs that can be displayed one after the other as a stereoscopic movie. The resulting sequence of stereoscopic images is displayed on a display device

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such as a television or computer screen, and its three-dimensional features are observed with the aid of conventional stereoscopic glasses. The original sequence of images is obtained by standard techniques using standard equipment and can comprise, for example, frames taken with a video camera or a digital still camera, or analog images that are scanned to produce the digitized images. The analog images can be images taken with a still or movie camera.

The method of the invention is highly automated and its various steps are carried out with a processor unit using known algorithms that familiar to persons skilled in computer vision.

In order to describe the method of the invention, we first consider an idealized example. In this case, the method is applied to a sequence of images from a video film photographed by a walking person using a commercial hand-held video camera.

Fig. 1 shows a scene consisting of two houses and a tree which the photographer records as he walks along the street at a uniform rate. Fig. 2 shows schematically how the scene of Fig. 1 would appear on the film. A whole frame (frame 7) has been outlined in bold lines as an example. The consecutive frames are the images from which the stereoscopic series of images will be generated.

Fig.2 shows an idealized situation in which the camera moves with constant velocity, i.e. the motion is linear translational motion at a constant speed. In this case, the frames of the film are aligned as shown with the right side of each frame designated by the numeral  $n$  and the corresponding left side by  $n'$ . In this idealization, an object, for example the small house, is entirely visible in two consecutive frames (7 and 8). A single feature of the same object, for example the right side of the door, appears in four frames (6-9) and a part of the object in six frames (5-10).

Fig. 2 does not take into account the fact that the scene being photographed is three-dimensional and is made up of three-dimensional objects. The three-dimensionality of the objects, combined with the fact that a real camera lens has a field of view, i.e. the width of the scene captured on the film is proportional, amongst other factors, to the distance between the objects and the focal length of the lens, means that each successive frame containing a given object contains a different amount of information about that object (unless of course the distance and orientation between lens and object have not changed from frame to frame). Figs. 3A to 3F schematically show the different information about the small house that is contained in each of the frames of Fig. 2 in which at least part of the house is visible. Figs. 3A to 3F show the scene as if it has no depth dimension. As discussed above, real objects in the scene are three-dimensional and therefore, for

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example, the frame shown in Fig. 3A would also include information about the left side of the house in an actual video film.

An actual video film would also differ from the ideal situation described above because of the non-uniformity and non-linearity of the motion of the camera that occurs under ordinary circumstances.

In Fig. 4A is schematically shown the intersection of the line-of-sight of the camera with the scene being photographed for the idealized case of Fig. 2 (solid line) and a more realistic case (dotted line). In the realistic case, the line-of-sight of the camera moves irregularly for many reasons, some as a result of voluntary actions of the photographer some not under his control. One of the most important factors is the desire to record the most prominent and/or most interesting features in the scene. This desire will, for example, result in the lens being pointed downward when photographing the small house, raised abruptly to record the large house, and raised again to record the distant tree. Also the photographer might pause opposite the small house to record more details and then hurry past the large house but, after passing the tree turn his camera back to photograph the now visible side of the large house. In addition, the camera might be inadvertently and irregularly moved by the inability of the photographer to hold it steady, due to factors such as uneven terrain, tiredness, strong winds, etc. As an extreme example, the photographer might even stumble. It must also be

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remembered that all of the objects in a scene might not be motionless and attempts to track a moving object will also contribute to a non-uniform progression of frames across the scene.

Fig. 4B schematically shows six consecutive frames of a video film illustrating the effect of motion of the lens. Frame 2 nearly falls on frame 1 indicating that the camera has been held steady and moved slowly relative to the scene. Between frames 2 and 3, the camera has been raised abruptly and moves rapidly horizontally, in frames 4 and 5 it is slowly lowered, and in frame 6 rotated.

The method of the invention will now be described in general terms and the computational details will be described hereinbelow. The production of a stereoscopic series of images from a series of images of a scene is accomplished, according to the method of the invention, by using a processor unit to execute a series of computational steps.

In the first step, the original series of images is placed in a device that is capable of digitizing the images, if necessary, and storing the images in the memory of the processor for further processing. Commonly available equipment, including personal computers, provides suitable hardware with which to carry out the processing of the images. A subset, containing images of a scene of interest, is selected and, using algorithms from the field of

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computer vision, affine transformations describing the approximate motion from one image of the series to its neighboring one are computed and stored.

One image of the subset is selected from the memory and the remaining images of the subset are examined, starting with the immediate neighbors of the selected frame and continuing with the next image, until an image is found that satisfies a predetermined criterion that assures that the image being examined is suitable to be used as a stereo partner for the selected image. The search is carried out in both directions and limitations are put on the number of image that are checked in each direction to limit the computational requirements on the one hand and not to ultimately obtain results that, while computationally correct, will not result in a realistic three-dimensional image.

Once a suitable partner has been found, it is used together with the selected image and the cascaded affine transformation between them to calculate a planar transformation. This planar transformation is now applied to the suitable stereo partner to obtain a stereo pair composed of the selected image and the transformed suitable image found in the search.

The first stereoscopic pair has now been created and the process is now repeated for another image until suitable partners have been found for all of the images of the subset.

It will be clear to skilled persons that the computational details of the method can be carried out in alternate ways that will yield essentially equivalent results. For example, applying the method of the invention as described, the final stereo pair is composed of the originally selected image and of a transformed image of the partner found by applying the parallax criterion. Similarly, if the affine transformations between images  $i$  and  $j$  are represented by  $A_{ij}$  then the transform between two images can be calculated directly between them at every stage of the calculation or can be calculated by cascading  $A_{ij}$ ,  $A_{jk}$ ,  $A_{kl}$ , etc. until the desired cascaded transform is achieved. In this last method the affine transformations between every neighboring pair of images in the subset is computed at the beginning of the calculation and stored in the memory for latter use.

The method of the invention is capable of producing the stereo pairs, even from a sequence of images taken with a hand-held camera as described hereinabove and containing all of the deviations from uniform motion of the camera relative to the scene discussed, as long as certain basic conditions are satisfied.

The most important of these conditions is that the original two-dimensional images must be recorded in a way which allows parallax between at least some of the images in the series. If, for example a camera is panned in a

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horizontal plane about a vertical axis passing through the optical center of the lens, then no parallax can exist between any of the images and the method of the invention can not be applied. If, however, the vertical axis is offset even by a small amount from the center of the lens, then there will be a translational component to the motion and parallax exists.

The degree of parallax that exists between two images is the criterion that is used to determine the appropriate choice of a partner that forms the stereo pair of a selected first image. Generally, the method uses the minimum amount of parallax that will result in satisfactory stereo pairs. If the amount of parallax is excessively large, then the result is displeasing to the eye and also demands a great deal of computational effort and time. It has been found that in most cases a partner for any given image is found between 4 to 18 frames away, the number depending on the speed of motion of the camera relative to the scene. In applying the method of the invention, the operator supplies a parallax criterion. The parallax criterion is a number of pixels, which expresses the horizontal translational motion of the center of an image to its position in its partner image this number is determined from the affine transformation calculated between two images. At each step in the search for a suitable stereo partner to a given image the affine transform is determined, if the center of the image has moved less than the parallax criterion then the search continues to images progressively further away from the selected image until the motion is equal

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to or greater than the parallax parameter. If no suitable stereo partner is found within the allowed limits of the search then various computational methods can be used to overcome this problem. It has been found that simply using the image for which the transformation gives the closest agreement with the parallax criterion gives satisfactory results in virtually all cases and this is the method used in the preferred embodiment of the invention.

A second condition is that the motion of an object being photographed in the original sequence of images can not be too fast relative to the rate at which the images are recorded. If this is the case then there will be too much parallax between successive images to obtain acceptable results.

Another condition relates to motion of an object in the scene being photographed. In this case, the transformation of the images will be optimal either for the moving object or for the background - if for the background, then the object will be blurred, and vice versa. The slower the motion of the object the less this effect will be observed in the final stereo movie.

A final condition for optimal use of the method of the invention is concerned with the treatment of the images at the beginning and end of the subset. In this case there are either not enough or no neighboring images available in

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which to find a suitable stereo pair. Practically, this problem is satisfactorily overcome as described for the case of the parallax criterion.

Fig. 5 is a series of images taken from six consecutive frames of a video film taken with a hand-held commercial home video camera. These images represent a typical segment of a film that was made into a stereoscopic series of images using the method of the invention. The general logic of the algorithms employed in the preferred embodiment of the invention will now be discussed and the results of the transformations for a single stereo pair will be shown in Fig. 6.

The starting point is a given scene  $Z$  comprising  $n$  images,  $Z = \{i_1, i_2, \dots, i_n\}$ . An image registration technology algorithm [for an example of a suitable algorithm see, Brown, Lisa G., A Survey of Image Registration Technology, ACM Computing Surveys, Dec. 1992, Vol. 24, No. 4, pp. 325-376.] is now applied to each image in the scene resulting in a collection of affine transformations between the images.

To limit the extent of the search for a suitable stereo partner for each image in the original scene, numbers  $s$  and  $f$  are chosen such that  $s > 1$  and  $f < n$ . For the images in the partial scene  $Z_s = \{i_s, i_{s+1}, \dots, i_f\}$ , the stereoscopic pair is determined by cascading the previously determined affine transformations

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until the translational element of the cascaded transformation is equal to, or greater than, the parallax criterion.

As an example of how this last step is performed, we take image  $i_k$  that is a member of partial scene  $Z_s$ . The affine transformation from  $i_k$  to image  $i_{k+1}$  is determined. If the translational element of the transformation is equal to or greater than the parallax criterion, then  $i_k$  and  $i_{k+1}$  form a stereo pair. If not, and also the sign of the translational element is opposite to that of the parallax criterion, then the affine transformation from  $i_k$  to  $i_{k+1}$  is calculated. If the translational element of the transformation is equal to or greater than the parallax criterion, then  $i_k$  and  $i_{k+1}$  are a stereo pair, if not then the computations continue in the same manner until image  $i_{k+j}$  (where  $j$  can be either positive or negative) which is suitable to form a stereo pair with  $i_k$  is reached.

To the images of the chosen stereo pair is applied an algorithm to compute the planar transformation,  $T_p$  between the two images [for an example of a suitable algorithm see: Burt, P.J. et. al., Object Tracking With Moving Camera, in Proceedings IEEE Workshop on Visual Motion 1989, pp. 2-12].

Now, for each image  $i_k$ , where  $s-1 < k < f+1$ , the transformed image  $i_k$ , where  $0 < k' < n$ , is obtained that is a stereo partner to  $i_k$ . Also the planar transformation  $T_p(k)$  between them is obtained. Using this transformation

the images  $k'$  are re-sampled, where  $k$  and  $k'$  are a stereo pair. The result of the sampling is the associated partial scene  $Zs' = \{i_s', i_{s'+1}', \dots, i_r'\}$ . Synchronized projection of the partial scene and the associated partial scene alternately to the right and left eyes will give the illusion of three-dimensions.

Fig. 6 shows the results of applying the method of the invention to one of the images shown in Fig. 5. By use of the object tracking algorithm, it was decided that the appropriate stereo partner for the image in frame 1050 is that in frame 1054. Frame 1054w is the image of 1054 after transformation, so that 1050 and 1054w are the stereo pair that are presented, respectively, to the two eyes. Fig. 7 shows the stereo pairs for each of the images of Fig. 5.

The spectator observes the series of images with the aid of a suitable device to separately deliver the images of the stereoscopic pair to the appropriate eye. An example of such a viewing device is a pair of shuttered liquid crystal display (LCD) glasses such as those produced by Stereographics Corporation. These glasses work in synchronization with the computer or projector to alternately block one eye while the frame intended for the other eye is displayed. If the rate of projection is, for example 30 frames per second, i.e. 15 frames per second for each eye, then the image seen by the right eye is retained while the image of the left image is seen separately by left eye. The brain then fuses the two images to give the impression of a three-dimensional image from the pair of two-dimensional ones.

Because each of the original consecutive images becomes one member of the consecutive stereoscopic pairs in the stereoscopic movie produced by the method of the invention and the order of the images is maintained in the resulting movie, any sound track recorded with the original sequence of images can be reproduced essentially unchanged in the stereoscopic movie.

It is to be noted that the method "searches" the sequence of images in both directions to account for irregular motion of the camera relative to the scene. In addition, persons experienced in the art will know how to reduce the amount of computation time by, for example, skipping over repetitive frames where there is essentially no information disclosed that was not present in previous frames. Standard editing techniques can also be employed, for example to "smooth out" the stereoscopic film at places where there occur discontinuities in the original video.

Although embodiments of the invention have been described by way of illustration, it will be understood that the invention may be carried out with many variations, modifications, and adaptations, for example by using a different order and/or types of transformations, without departing from its spirit or exceeding the scope of the claims.

**Claims**

1. A method for producing a series of stereoscopic pairs of images that can be displayed one after the other as a stereoscopic movie from a sequence of consecutive images of a scene, wherein said sequence of images is obtained by standard techniques using standard equipment and wherein a first image of a pair of images comprising the right and left images of each frame of said stereoscopic series of images is selected from the original sequence of images, and its stereo partner is either selected from said original sequence and/or is generated by transforming images selected from said original sequence of images.
2. A method according to claim 1, wherein the sequence of images is chosen from frames taken with a video camera or a digital still camera.
3. A method according to claim 1, wherein the sequence of images are analog images that are scanned to produce the digitized images.
4. A method according to claim 3, wherein the analog images can be images taken with a still or movie camera.
5. A method according to claim 1, comprising the following steps:

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- a) processing the original sequence of consecutive images of a scene by use of a device that is capable of reading the individual images, digitizing the images if necessary, and storing the images in a memory unit;
- b) selecting a subset of images of interest;
- c) computing the collection of affine transformations between the images in the subset;
- d) selecting one image of the sequence of the subset of images of a scene that will be one member of the first stereo pair of the sequence;
- e) searching for a suitable stereo partner for said selected image by determining the cascaded affine transformation to each of the successive images starting with the neighboring image to said selected image and applying the parallax criterion until a suitable stereo partner, i.e. an image that can be transformed into the second member of said stereo pair is found;
- f) calculating a planar transformation by using the members of said stereo pair and the cascaded affine transformation between the members of said pair;
- g) applying said planar transformation to said selected image;
- h) storing said stereo pair in the memory unit; and
- i) repeating steps c) through h) for the next and each of the remaining images of said selected subset.

6. A method according to claim 4, wherein said parallax criterion is expressed as a number of pixels of horizontal translational motion.
7. A method according to claim 4, wherein said searching is carried out amongst said neighboring images on both sides of said selected image.
8. A method according to claim 4, wherein said searching is limited to a maximum number of images on either side of said selected image.
9. A series of stereoscopic pairs of images produced from a sequence of consecutive images of a scene, wherein said sequence of images is obtained by standard techniques using standard equipment and wherein a first image of a pair of images comprising the right and left images of each frame of said stereoscopic series of images is selected from the original sequence of images, and its stereo partner is either selected from said original sequence and/or is generated by transforming images selected from said original sequence of images.
10. A series of stereoscopic pairs of images produced from a sequence of consecutive images of a scene, wherein said sequence of images is obtained by use of the method of claims 1 to 8.

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11. A stereoscopic movie produced from the series of stereoscopic pairs of images of claims 9 or 10.
12. A stereoscopic movie according to claim 11 and additionally accompanied by a sound track, wherein said sound track is essentially identical to the sound track recorded with the sequence of consecutive images from which said stereoscopic movie is produced.

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Fig. 1

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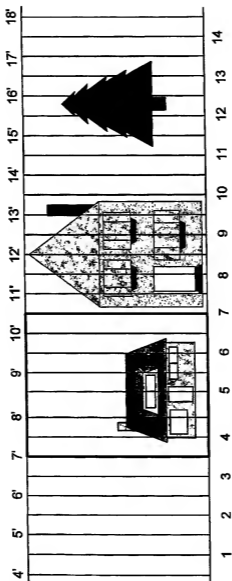


Fig. 2

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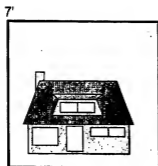


Fig. 3A 7

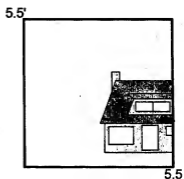


Fig. 3D

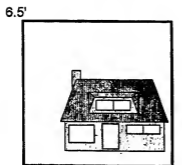


Fig. 3B 6.5

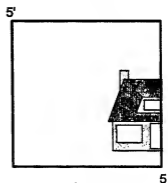


Fig. 3E 5

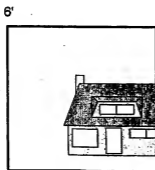


Fig. 3C 6

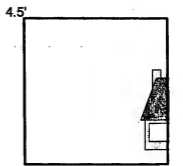


Fig. 3F 4.5

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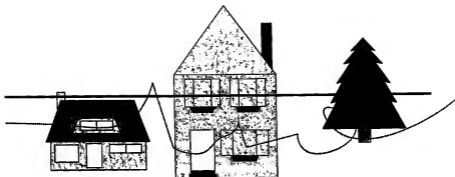


Fig. 4A

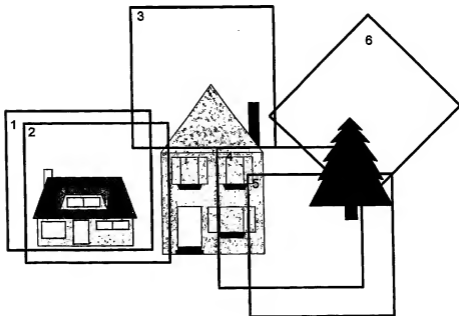


Fig. 4B

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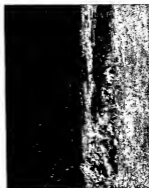


1050

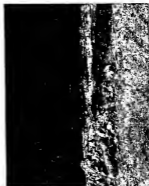


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1054

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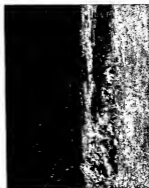


Fig. 5

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1054



1050



1054w

Fig. 6

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1050



1051



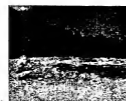
1052



1053



1054



1055

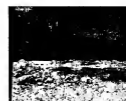


Fig. 7

A. CLASSIFICATION OF SUBJECT MATTER  
IPC 7 H04N13/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 H04N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 925 294 A (GESHWIND DAVID M ET AL) 15 May 1990 (1990-05-15) column 1, line 13 - line 19 column 2, line 66 - column 3, line 46; figure 1	1-4,6-12
X	US 6 314 211 B1 (KIM MAN-BAE ET AL) 6 November 2001 (2001-11-06) column 1, line 21 - line 47; figures 1,2 column 4, line 4 - line 33; figure 3	1-4,6-12
A	US 6 215 516 B1 (MA KELVIN ET AL) 10 April 2001 (2001-04-10)	
A	EP 0 735 512 A (SANYO ELECTRIC CO) 2 October 1996 (1996-10-02)	

-/-

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

19 September 2003

Date of mailing of the international search report

30/09/2003

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## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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